UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Power Quality and Submetering Device

Final Presentation

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4/26/2024

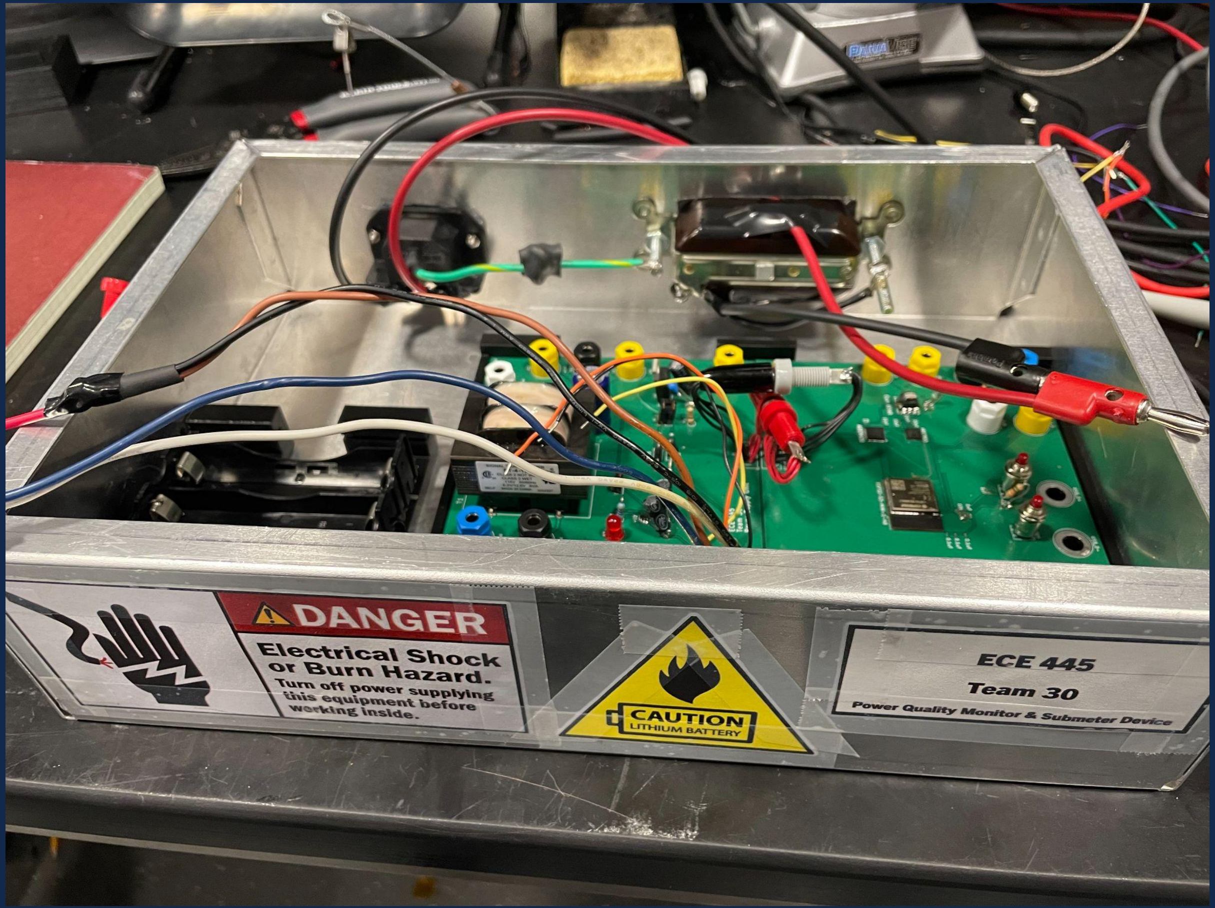
PROJECT INTRODUCTION & OVERVIEW

Why did we decide to design a submetering device?

- In the rapidly evolving field of power electronics and energy technologies, maintaining consistent and high-quality power distribution and energy usage is critical for residential and commercial buildings.
- Using submeters can create energy savings, lower operating costs, increase building efficiency and reliability, and improve occupant comfort.
- **However, devices today can be cost-inefficient, complex to operate and to read, and they may lack real-time insights.**

These shortcomings lead to difficulty in meeting recent sustainability efforts, and as such, an innovative solution is needed.


www.ece445projteam30.com
Power Outlet Values
Load Values
Notifications
Google Cloud


DANGER
Electrical Shock or Burn Hazard.
Turn off power supplying this equipment before working inside.
CAUTION
LITHIUM BATTERY
ECE 445
Team 30
Power Quality Monitor & Submeter Device

Overview of Subsystems

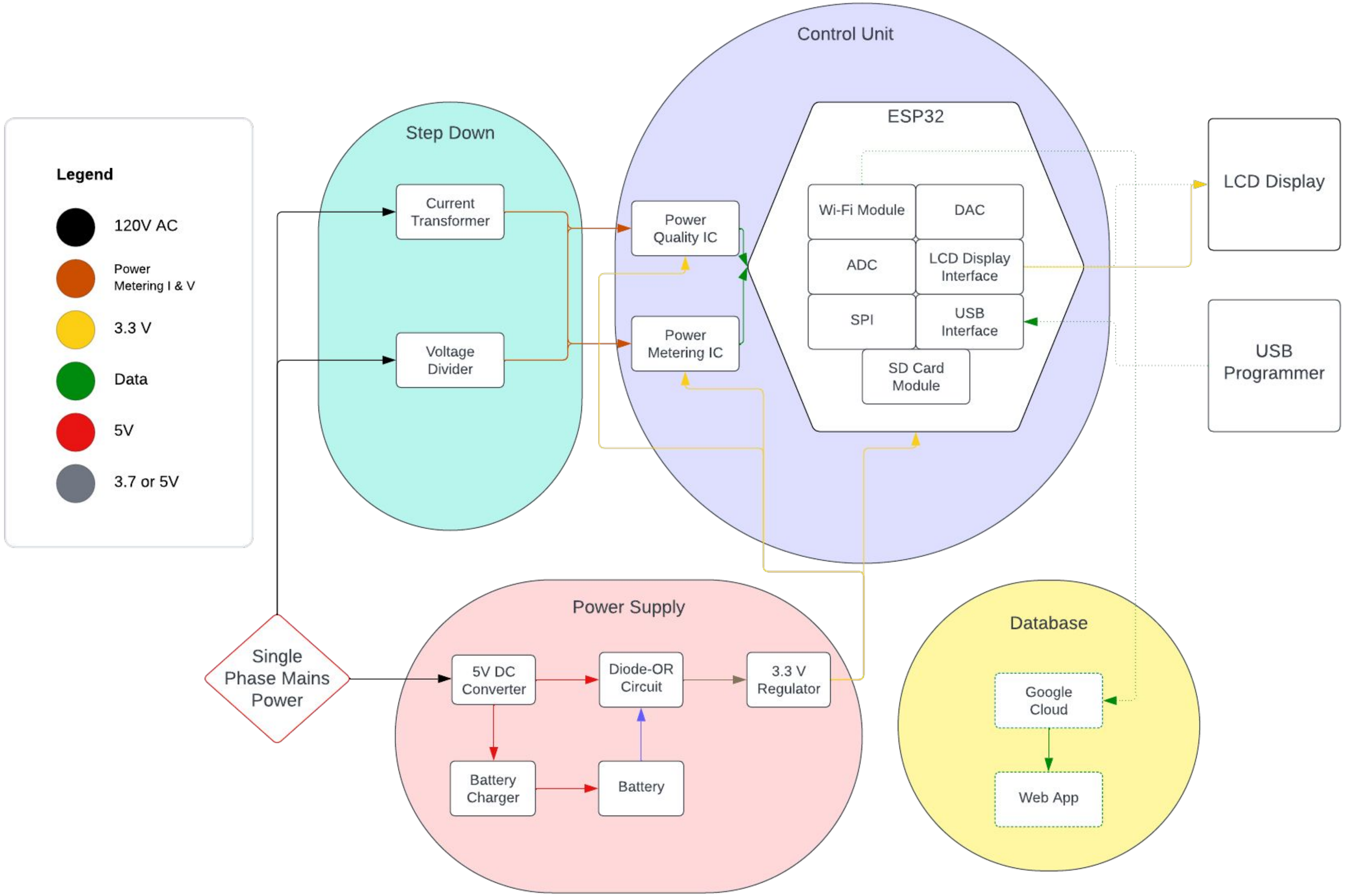
Power Supply — Convert 120V AC → 3.3V DC

Step Down — Convert down AC wall voltage and current

Control Unit — Measure down converted V & I via SPI, send to database

Database — Store and display measured data

Block Diagram



SD Card and LCD Display

- **After discussion among ourselves and with our TA, we decided to eliminate the SD card and LCD display components.**
- **The spirit of our project is fundamentally to deliver recorded data to the user.**
  - The SD Card and physical display are inherently less reliable, slower, and more expensive than their digital counterparts.
- Functionality is **gained** rather than lost, and fewer consumer interference points are made.

High Level Requirements

For our project to be considered successful, there are three high-level criteria that must be met.

Our device should be able to perform the following tasks:

I. Sample a single-phase input for its voltage and current (within 10%).

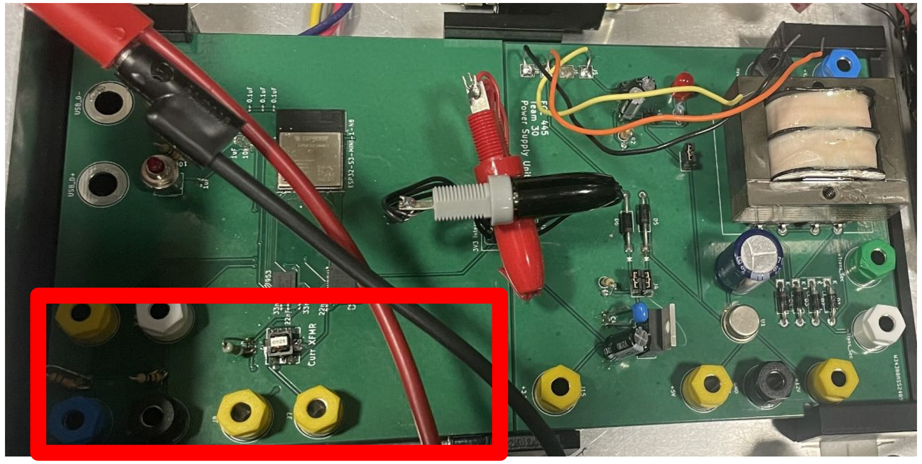
II. Use a microcontroller to process the voltage and current samples and calculate apparent and real power. Store data to a database (every 10 seconds). Waveforms will also be displayed.

III. Notify the user (within 5 seconds) of any disturbances in measurements outside of a set tolerance (wall voltage ±5%) and of any failures.

SUBSYSTEM REQUIREMENTS, VERIFICATION, & DEMO RESULTS

1) Step Down Unit

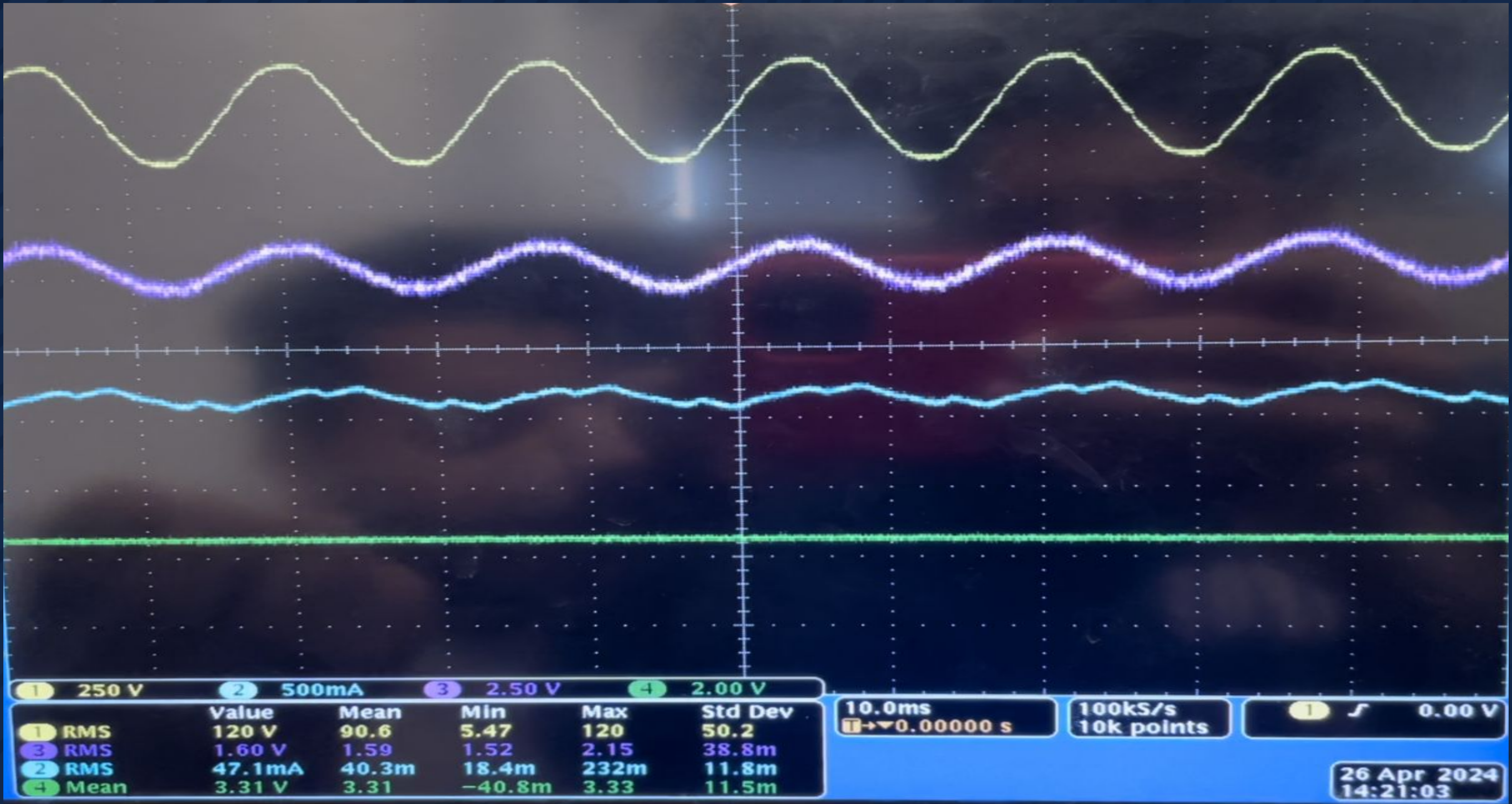
Step Down Unit



115V : 10V Voltage Transformer

1:200 Current Sense Transformer

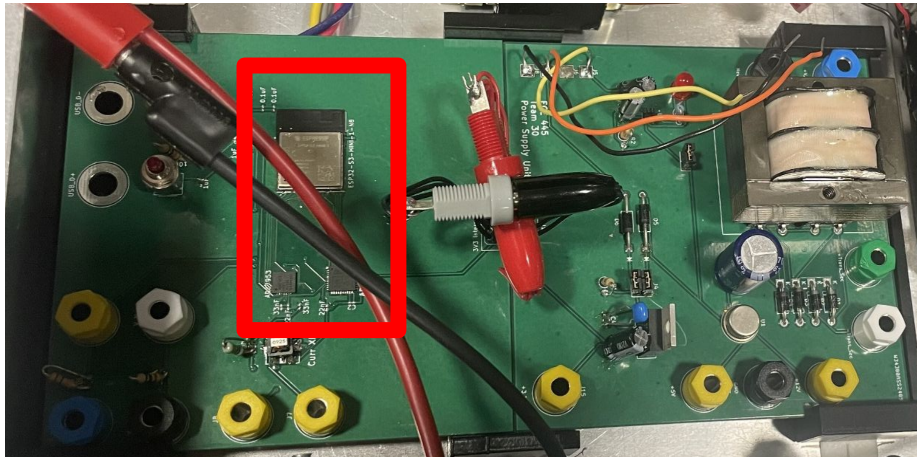
Requirements	**Verification**
Step Down Voltage from 120V RMS to <3.4V since the ICs cannot handle a voltage higher than that	Send an AC waveform smaller than the wall voltage through the divider Observe that it steps down to 3.4V ±2%
Step Down Current from (max) <15A to ~<75mA	Send an AC waveform smaller than the wall voltage through the transformer Observe that the current steps down to 75mA ±5%

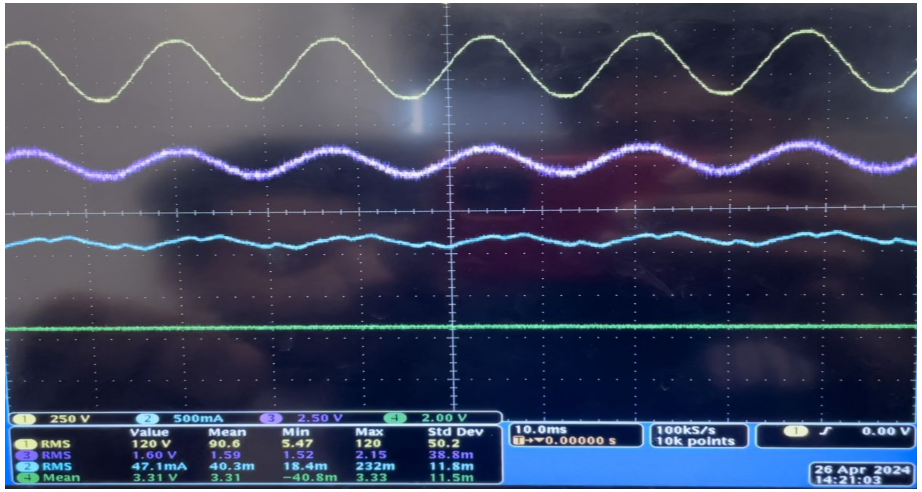


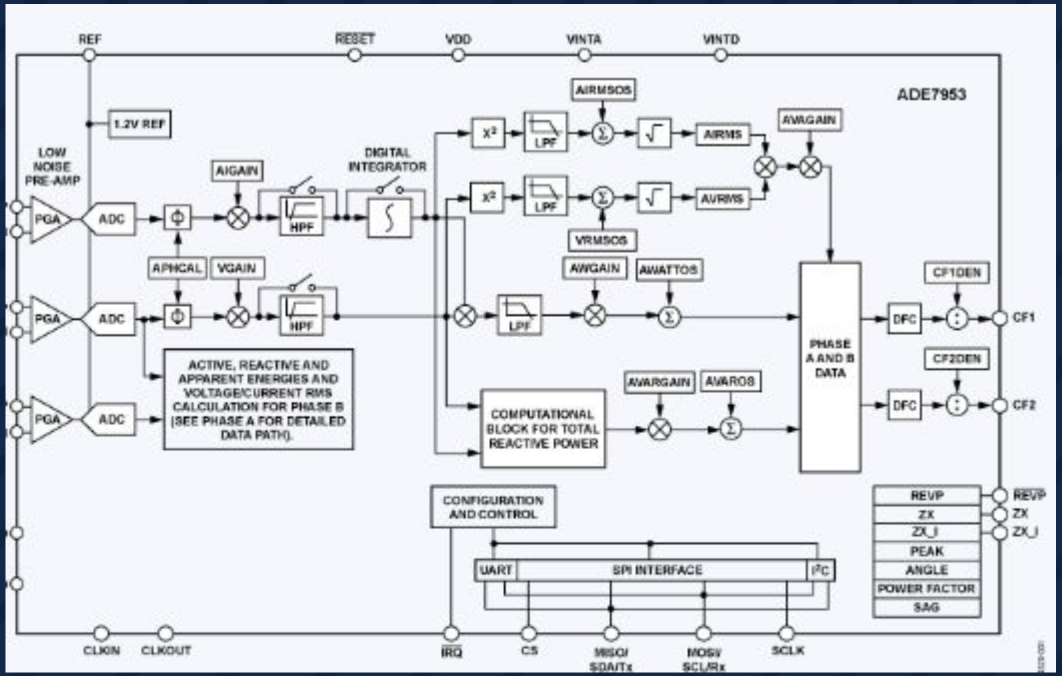
1 250 V
2 500mA
3 2.50 V
4 2.00 V
Value Mean Min Max Std Dev
1 RMS 120 V 90.6 5.47 120 50.2
3 RMS 1.60 V 1.59 1.52 2.15 38.8m
2 RMS 47.1mA 40.3m 18.4m 232m 11.8m
4 Mean 3.31 V 3.31 −40.8m 3.33 11.5m
10.0ms
T→▼0.00000 s
100kS/s
10k points
1 0.00 V
26 Apr 2024
14:21:03

2) Control Unit

Requirements	Verification
Original voltages and currents should be sent to the ESP32 from the measurement ICs and be accurate to ±5%	Send a small AC waveform directly to the ICs and record the data directly to On-Chip Memory as a calibration test Give 3.3V to VDD and Vin for the ICs and ESP32 respectively Use the wall as a source testing the step down and control unit subsystem at the same time, under no load and low load condition







ADE7953: Metering IC

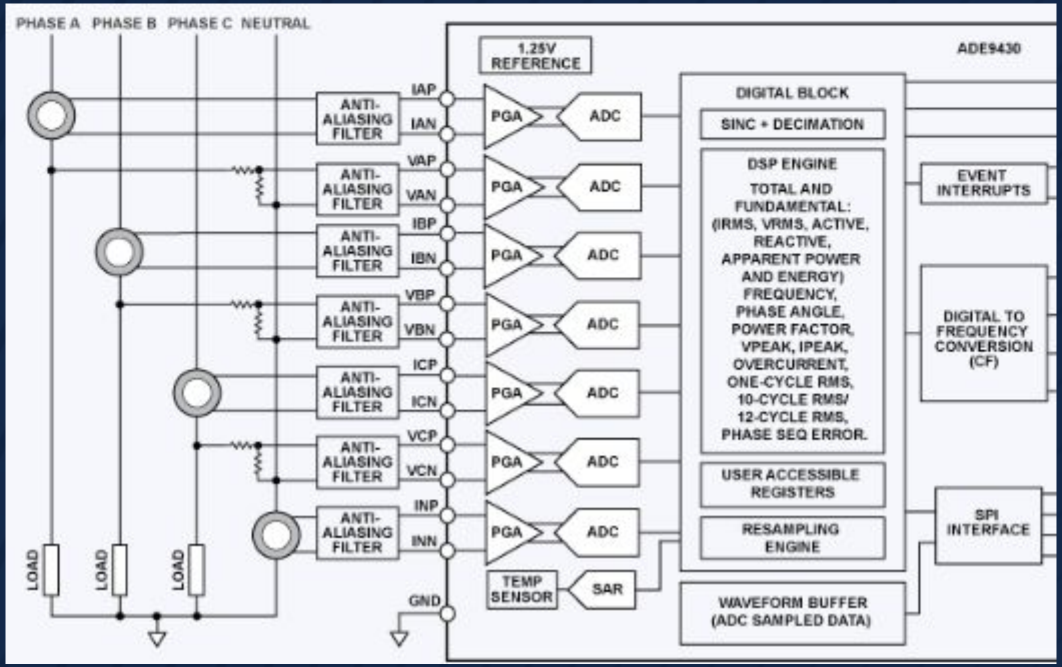
Measures:

- Power - Active, Reactive, and Apparent
- Sampled Current
- RMS Voltage

Measures:

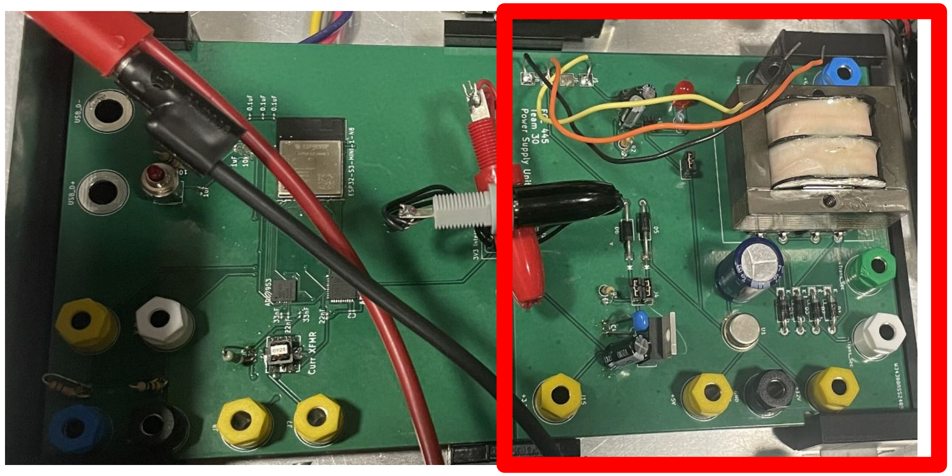
- Dips and swells
- Interruptions
- Flicker
- Under and over deviation
- Magnitude
- Harmonics
- Interharmonics
- Unbalance
- THD

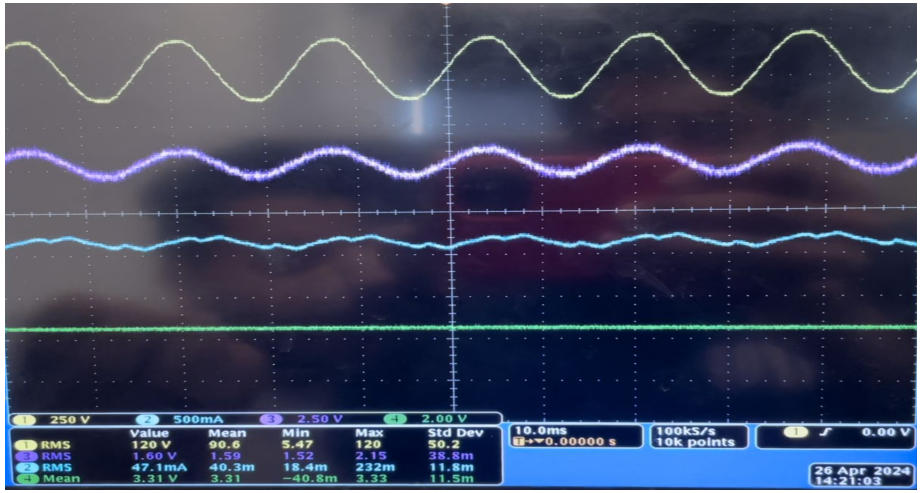
ADE9430:Power Quality IC



3) Power Supply Unit

Power Supply Unit





Requirements	Verification
Convert 120V AC to 3.3V DC and deliver to Control Unit	Use a multimeter to probe test points on Power Supply, supplying intermediate voltages (testing 120V AC last) to ensure safety

Power Supply Unit (continued)

Switch between wall powered and self-powered modes in the event of a blackout without loss of operation	Simulate a blackout by removing wall power and validate that 3.3V is still being delivered to some load at the output of the supply

Power Supply Unit (continued)

In self-powered mode, system should run for >10 hours	Fully charge battery and run system powering an analog bit adder counter circuit Verify that the battery operates for more than 10 hours

1500 mAh / 150 mA = 10 hours

- ➔ Discharge current measured to be less than 150 mA
- ➔ Note that such a deep discharge should not be regular practice and would ideally only occur if absolutely necessary

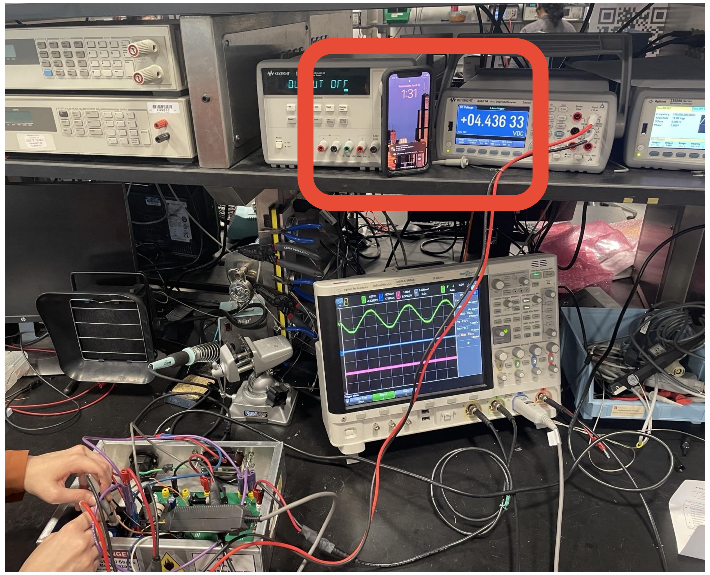
Specifications

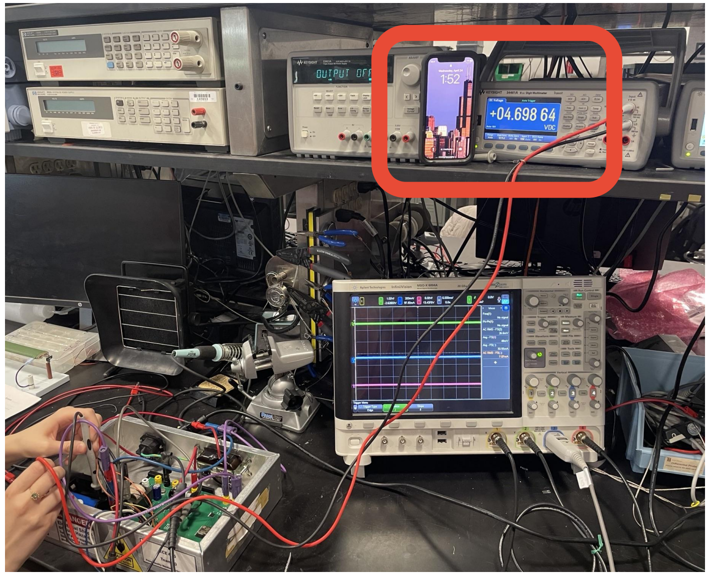
Electrical Characteristics	Nominal Voltage	3.2V
	Nominal Capacity	1500mAh 0.2C discharge, room temperature
	Internal Resistance	≤ 40mΩ (1kHz AC / fully charged)
	Cycle Life	≥ 2000 cycles@ 0.2C discharge, room temperature
Charge	Charge Voltage	3.65 ± 0.03V
	Charge Current	300mA
	Max. Charge Current	750mA
Discharge	Max. Discharge Current	4500mA
	Discharge Cut-off Voltage	2.0V

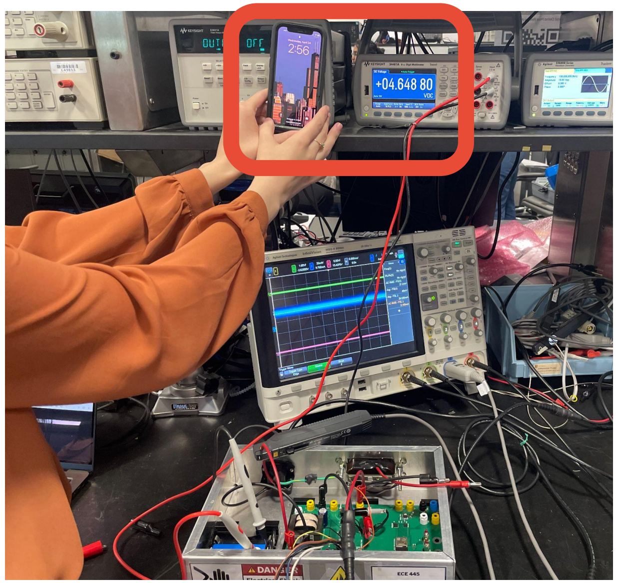
Power Supply Unit (continued)

Charging circuit protections: charging battery to 80%, at rated current maximum	Probe battery voltage and current every 15 minutes when charging from low voltage (<4V) Verify voltage does not exceed 80% of rated value

$$0.8 \times 6.4\ V = \mathbf{5.12\ V}$$

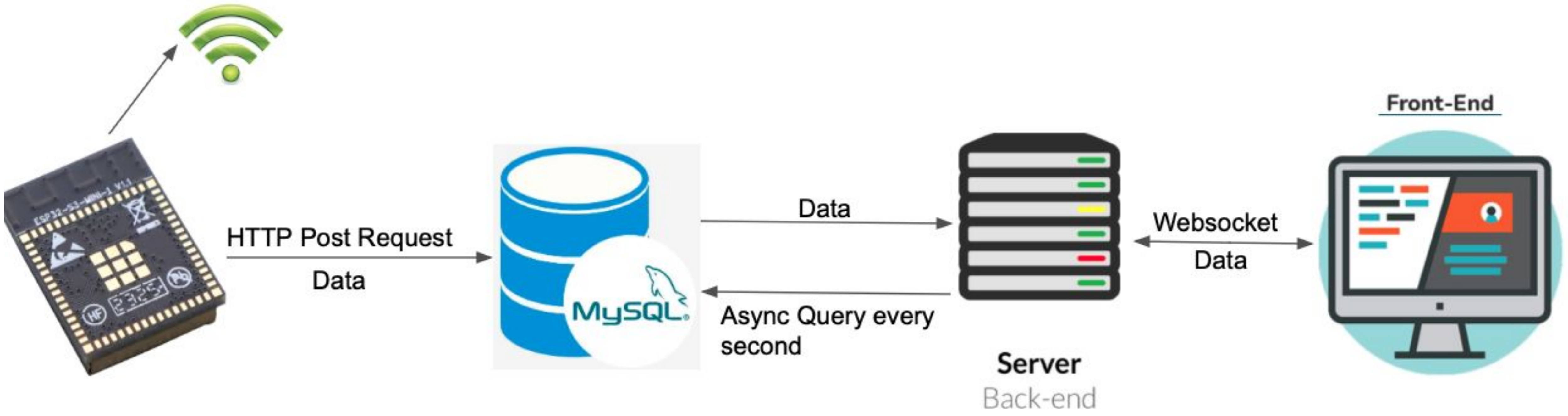






4) Database Unit

Database


HTTP Post Request
Data
MySQL
Data
Async Query every second
Server
Back-end
Websocket
Data
Front-End

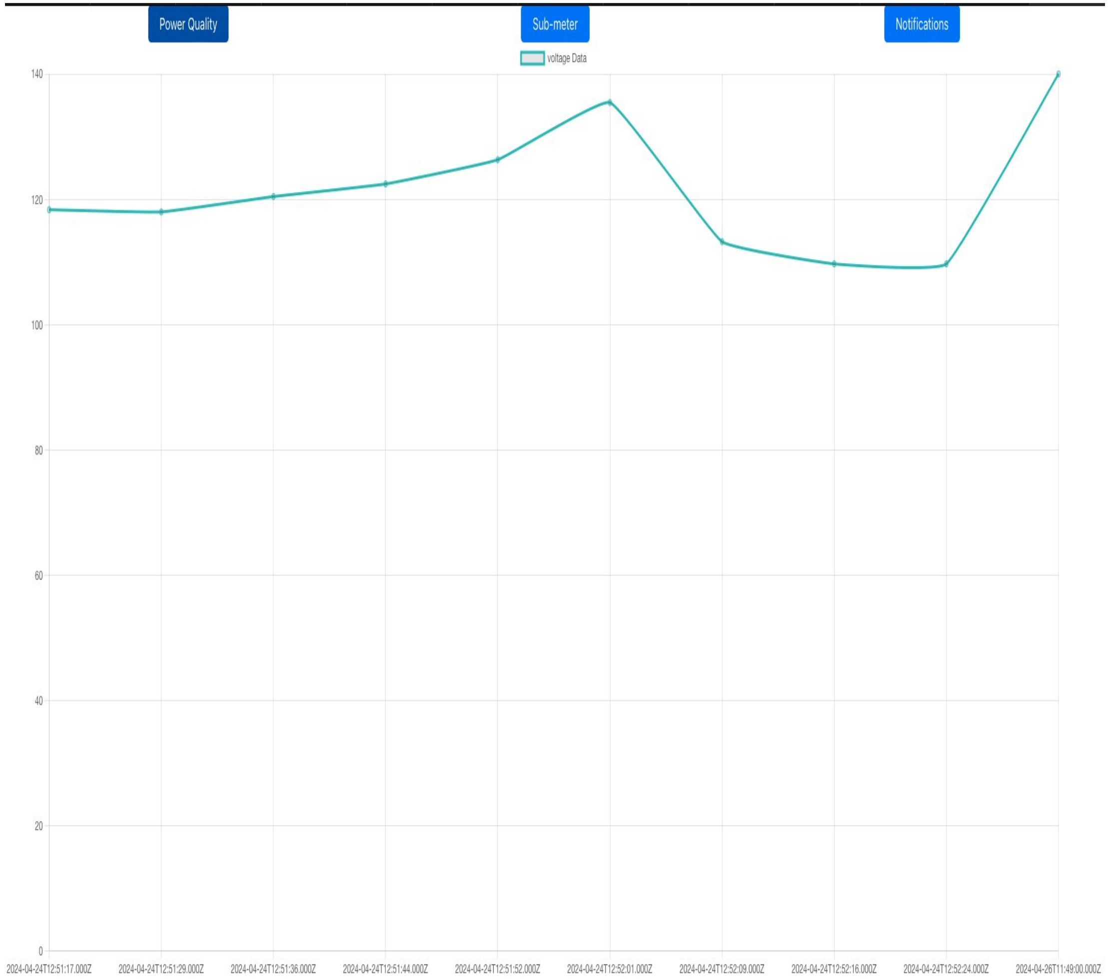
Database (continued)

Requirements	Verification
The database must store new data once every 10 seconds from the ESP32.	Set up ESP32 Wi-Fi connection and establish HTTP connection with Google Cloud database. Send fake time, voltage, and current data once every 10 seconds for 5 minutes from ESP32. Use “SELECT *” statement in Google Cloud terminal to see all the data. For success, we would need at least 29/30 data sets to be correctly present.

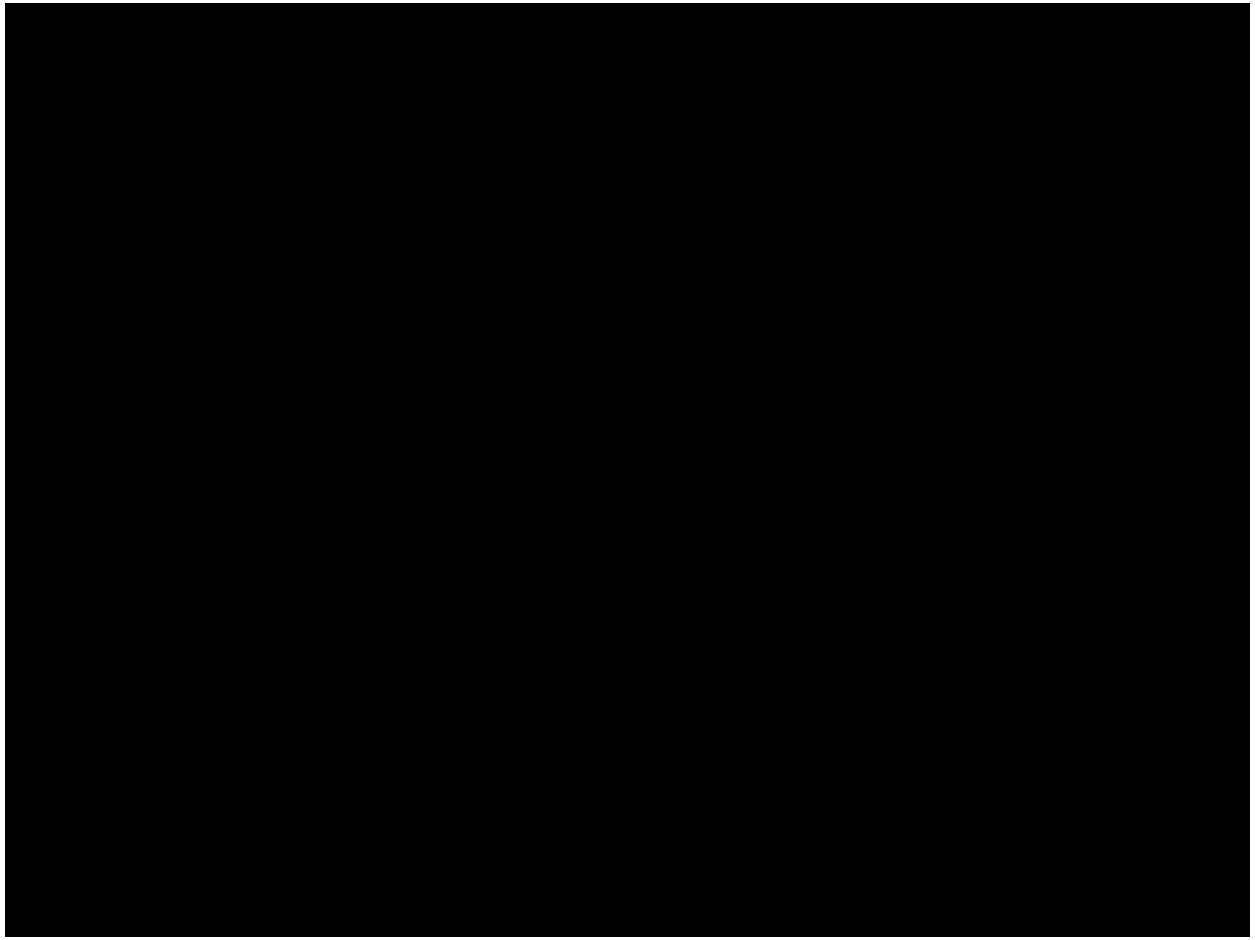
```
mysql> SELECT * FROM PowerData;
+---------+-------------+-----------+---------------------+---------+---------+----------------+------------+
| data_id | outlet_name | load_name | measurement_time    | voltage | current | apparent_power | real_power |
+---------+-------------+-----------+---------------------+---------+---------+----------------+------------+
|       0 | ECEB        | CHARGER   | 2024-04-24 07:50:22 |  122.31 |    3.11 |         380.38 |     380.38 |
|       1 | ECEB        | CHARGER   | 2024-04-24 07:50:27 |  121.44 |    3.06 |         371.61 |     371.61 |
|       2 | ECEB        | CHARGER   | 2024-04-24 07:50:37 |  119.23 |    3.09 |         368.42 |     368.42 |
|       3 | ECEB        | CHARGER   | 2024-04-24 07:50:43 |  117.68 |    3.02 |         355.39 |     355.39 |
|       4 | ECEB        | CHARGER   | 2024-04-24 07:50:56 |  123.11 |    3.11 |         382.87 |     382.87 |
|       5 | ECEB        | CHARGER   | 2024-04-24 07:51:08 |  121.22 |    3.27 |         396.39 |     396.39 |
|       6 | ECEB        | CHARGER   | 2024-04-24 07:51:17 |  118.33 |    3.06 |         362.09 |     362.09 |
|       7 | ECEB        | CHARGER   | 2024-04-24 07:51:29 |  117.98 |    3.12 |         368.10 |     368.10 |
|       8 | ECEB        | CHARGER   | 2024-04-24 07:51:36 |  120.43 |    2.95 |         355.27 |     355.27 |
|       9 | ECEB        | CHARGER   | 2024-04-24 07:51:44 |  122.44 |    3.17 |         388.13 |     388.13 |
|      10 | ECEB        | CHARGER   | 2024-04-24 07:51:52 |  126.31 |    3.11 |         392.82 |     392.83 |
|      11 | ECEB        | CHARGER   | 2024-04-24 07:52:01 |  135.44 |    3.06 |         414.45 |     414.45 |
|      12 | ECEB        | CHARGER   | 2024-04-24 07:52:09 |  113.23 |    3.09 |         349.88 |     349.88 |
|      13 | ECEB        | CHARGER   | 2024-04-24 07:52:16 |  109.68 |    3.02 |         331.23 |     331.23 |
|      14 | ECEB        | CHARGER   | 2024-04-24 07:52:24 |  109.68 |    3.02 |         331.23 |     331.23 |
|      15 | ECEB        | CHARGER   | 2024-04-26 06:49:00 |  140.00 |    3.00 |         420.00 |     420.00 |
+---------+-------------+-----------+---------------------+---------+---------+----------------+------------+
16 rows in set (0.00 sec)
```

Database (continued)

The system must show a notification on the frontend when there's any disturbances (voltage fluctuations) outside of a set tolerance by 5%, or power failures. This notification must appear within 5 seconds.	Send fake time, voltage, and current data with the voltage set at 5% above 120Vrms, then the voltage set at 5% below 120Vrm. Repeat prior step but set the voltage to 0V to simulate a power failure. Start a stopwatch to count the time it takes for the notification to show up. Must see a notification on the frontend of the website within 5 seconds of sending the data.
The frontend must have a graph that shows voltage and current data that is refreshed at least once per minute.	Send fake time, voltage, and current data that is the exact same for 55 seconds. Change the data that is sent for the next 55 seconds. For every 1 minute, we must see the graph changing to reflect the correct data.



Database (continued)



CONCLUSIONS, LESSONS LEARNED, & FURTHER WORK

Successes and Lessons Learned

- ¾ Subsystems work as intended, hitting 2.5 of the 3 high level requirements
- Our design work in our PCBs could've been further improved and tested had we utilised the earlier windows
- Power Supply Board is something we are very proud of:
  - Further work includes adding heat sink on the linear regulator or replacing it with one rated for more intense/prolonged use to ensure better performance
- Control Unit Board must be redesigned:
  - Many potential points of error
    - Burnt IC's
    - Missing strapping resistors/ decoupling capacitors
    - Lack of probe points
    - Lack of Digital Model

Lessons Learned Cont.

- Control Unit Cont.
    - ESP32 Debugging
        - Resoldering, devboard replacement, skywires from PCB to devboard, new PCB.

- Battery Safety
    - Normalization after running discharge tests resulted in strange behavior (voltage increase under no load, decrease while charging, collapse under test load)

- IllinoisNet Permissions
    - Sending Requests or data over IllinoisNet seemed to be impossible
        - Authorization Token, or Permissions were not procured in time for demo

Further Work

- Website (Front End)
  - Improve visual style
  - Include information beyond waveforms
  - Add security features

- Re-Design Control Unit Board
  - Add Probe Points
  - Use different Microcontroller
  - Utilize through hole mounts for SMT ICs

- Power Supply Heat
  - Replace 5V - 3.3V Regulator or add heat dissipation system

Thank you!

Special thanks to Surya, Jason, the other TAs who have helped, our mentor Jack Blevins, and Professor Schuh!

Questions?

The Grainger College of Engineering

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